

Forward Neutron Production at MIPP Experiment

Analysis status report. Part II.

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outline

Previous meeting:

- The neutron spectra were presented. Their were corrected for the number of factors: HCAL acceptance, trigger efficiency and others. Most significant correction factor is due to of calorimeter acceptance.

Today:

- Systematic uncertainties
- Neutron production cross section
- Target atomic weight dependence

systematic uncertainty, outline

Forward neutron production cross section:

$$\sigma(p_n > p_{min}) = \frac{n_n(t-in) - n_n(t-out) - n_n(backgr)}{N_{beam} \times \epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}} \times \frac{1}{n_t}$$

Systematic uncertainty:

- Incident proton sample size
- Target-out sample size
- Trigger efficiency
- HCAL acceptance
- Neutron selection cuts
- Neutron backgrounds
- Target properties (?)
- Total systematics uncertainty

systematic uncertainty of the incident protons

target	p_{beam}	statistical	estim.syst.	assigned syst.
H_2	20	± 0.054	± 0.07	± 0.10
H_2	58	± 0.026	± 0.03	± 0.10
Beryllium	58	± 0.052	± 0.01	± 0.10
Carbon	58	± 0.028	± 0.02	± 0.10
Bismuth	58	± 0.018	± 0.05	± 0.10
Uranium	58	± 0.015	± 0.06	± 0.10
H_2	84	± 0.009	± 0.09	± 0.10
Beryllium	120	± 0.009	± 0.08	± 0.10
Carbon	120	± 0.012	± 0.07	± 0.10
Bismuth	120	± 0.009	± 0.08	± 0.10

Table 1: The statistical, estimated and assigned systematic uncertainties for the incident protons. The systematic uncertainties for the target-out sample size considered separately (next page).

systematic uncertainty of the target-out sample size

$$N_n(p_n > p_{min}) = \frac{n_n(t-in) - [n_n(t-out) \pm \Delta n] - n_n(backgr)}{\epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}}$$

tgt-p _{beam}	N _n (nominal)	CF _{t-out}	assign.var. ΔCF_{t-out}	N _n variations	syst _{t-out}
H ₂ -20	23649	0.50	±0.17	+24843 -22455	±0.050
H ₂ -58	254575	1.16	±0.10	+267455 -241723	±0.051
Be-58	11475	1.47	±0.16	+12755 -10235	±0.112
C-58	92874	1.39	±0.13	+96823 -88943	±0.043
Bi-58	66279	1.14	±0.10	+72338 -60280	±0.091
U-58	113005	1.09	±0.10	+124045 -102043	±0.098
H ₂ -84	314452	1.11	±0.10	+328634 -300271	±0.045
Be-120	79377	1.09	±0.10	+84762 -73992	±0.068
C-120	46493	1.25	±0.10	+48182 -44804	±0.036
Bi-120	58341	1.04	±0.10	+64653 -52029	±0.108

Table 2: CF_{t-out} is the correction factor applied to the target-out sample size. The assign.var. ΔCF_{t-out} is an assigned uncertainty in correction factor. N_n variations is corresponding variations on the number of neutrons. Last column is the systematic uncertainty.

systematic uncertainty of the trigger efficiency

$$N_n(p_n > p_{min}) = \frac{n_n(t-in) - n_n(t-out) - n_n(backgr)}{\epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}} \pm [0.10 \times \Delta N_{trig}]$$

tgt-p _{beam}	N _n (nominal)	ϵ_{trig}^{avr}	$\Delta\epsilon_{trig}(\text{ass})$	N _n (var.)	syst _{trig}
H ₂ -20	23649	0.46	± 0.10	+24900 -22399	± 0.053
H ₂ -58	254575	0.71	± 0.10	+261620 -247531	± 0.028
Be-58	11475	0.82	± 0.10	+11672 -11278	± 0.017
C-58	92874	0.84	± 0.10	+94097 -91651	± 0.013
Bi-58	66279	0.845	± 0.10	+67176 -65382	± 0.014
U-58	113005	0.845	± 0.10	+114483 -111526	± 0.013
H ₂ -84	314452	0.73	± 0.10	+322871 -306034	± 0.027
Be-120	79377	0.885	± 0.07	+80086 -78668	± 0.009
C-120	46493	0.905	± 0.05	+46742 -46244	± 0.005
Bi-120	58341	0.87	± 0.10	+59129 -57553	± 0.014

Table 3: The systematic uncertainty studies of the trigger efficiency. The $\Delta\epsilon_{trig}(\text{ass})$ is an assigned uncertainty.

$\Delta N_{trig} = N_n(\text{nominal}) - N_n(\text{without } \epsilon_{trig} \text{ applied})$ - it represents the size of ϵ_{trig} correction. $N_n(\text{var})$ represents the neutron sample size variations. Last column - the systematic uncertainty.

systematic uncertainty of the HCAL acceptance

Two approaches:

- use the difference between FLUKA and LAQGSM predictions
- assign the some reasonable uncertainty

tgt-p _{beam}	N _n (FLUKA)	N _n (LAQGSM)	syst _{hcac} (v1)	ε _{FLUKA} ^{hcac}	ε _{LAQGSM} ^{hcac}	cf ₁
H ₂ -20	23649	n/a	n/a	0.166		10
H ₂ -58	254575	241506	±0.051	0.523	0.627	4.14
Be-58	11475	12096	±0.054	0.492	0.528	3.95
C-58	92874	95362	±0.027	0.478	0.528	4.25
Bi-58	66279	61602	±0.076	0.348	0.451	5.61
U-58	113005	105435	±0.072	0.349	0.451	5.52
H ₂ -84	314452	n/a	n/a	0.680		2.5
Be-120	79377	86496	±0.090	0.835	0.775	2.02
C-120	46493	50599	±0.088	0.829	0.775	2.04
Bi-120	58341	62501	±0.071	0.714	0.710	2.30

Table 4: The syst_{hcac}(v1) is the systematic uncertainty of HCAL acceptance according to the first approach.

It looks **underestimated**.

HCAL acceptance systematics: approach 2

$$N_n(p_n > p_{min}) = \frac{n_n(t-in) - n_n(t-out) - n_n(backgr)}{\epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}} \pm [0.30 \times \Delta N_{hcal}]$$

tgt-p _{beam}	N _n (nominal)	N _n variations	syst _{hcal} (v2)	ε _{FLUKA}
H ₂ -20	23649	+29875 -17424	±0.263	0.166
H ₂ -58	254575	+292606 -216545	±0.149	0.523
Be-58	11475	+13229 -9721	±0.153	0.492
C-58	92874	+108201 -77547	±0.165	0.478
Bi-58	66279	+79746 -52812	±0.203	0.348
U-58	113005	+136044 -89965	±0.204	0.349
H ₂ -84	314452	+340231 -288674	±0.082	0.680
Be-120	79377	+83936 -74818	±0.057	0.835
C-120	46493	+49271 -43714	±0.060	0.829
Bi-120	58341	+63885 -52797	±0.095	0.714

Table 5: Middle column represents the neutron samples due to ±0.30*(corr-uncorr) variations in the HCAL acceptance correction. Last column - the systematic uncertainty (v2).

systematic uncertainty of the neutron selection cuts

$$N_n(p_n > p_{min}) = \frac{n_n(t-in) - n_n(t-out) - n_n(backgr)}{\epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}} \pm [0.30 \times \Delta N_{cuts}]$$

tgt-pbeam	N _n (nominal)	ϵ_{cuts}	N _n variations	syst _{cuts}
H ₂ -58	23649	0.801	+25162 -22137	±0.064
H ₂ -58	254575	0.866	+264983 -244168	±0.041
Be-58	11475	0.905	+11814 -11135	±0.030
C-58	92874	0.900	+95600 -90147	±0.029
Bi-58	66279	0.917	+67827 -64731	±0.023
U-58	113005	0.917	+115590 -110419	±0.023
H ₂ -58	314452	0.890	+325209 -303696	±0.034
Be-120	79377	0.898	+81820 -76933	±0.031
C-120	46493	0.903	+47844 -45142	±0.029
Bi-120	58341	0.916	+59796 -56886	±0.025

Table 6: Second column represents the neutron selection efficiency. Third column represents the N_n numbers for ±0.30×(corr-uncorr) variations in the correction value. Last column - the systematic uncertainty.

systematic uncertainty of the neutron backgrounds

$$N_n(p_n > p_{min}) = \frac{n_n(t-in) - n_n(t-out) - n_n(backgr)}{\epsilon_{trig} \times \epsilon_{hcal} \times \epsilon_{cuts}} \pm [0.30 \times \Delta N_{backgr}]$$

tgt-p _{beam}	N _n (nominal)	R _{fake}	N _n variations	syst _{backgr}
H ₂ -20	23649	0.007	+23701 -23598	±0.002
H ₂ -58	254575	0.082	+262434 -246716	±0.031
Be-58	11475	0.078	+11780 -11170	±0.027
C-58	92874	0.066	+95126 -90621	±0.024
Bi-58	66279	0.101	+68419 -64139	±0.032
U-58	113005	0.106	+116885 -109124	±0.034
H ₂ -84	314452	0.117	+325923 -302982	±0.036
Be-120	79377	0.192	+85024 -73730	±0.071
C-120	46493	0.169	+49413 -43573	±0.063
Bi-120	58341	0.218	+63045 -53637	±0.081

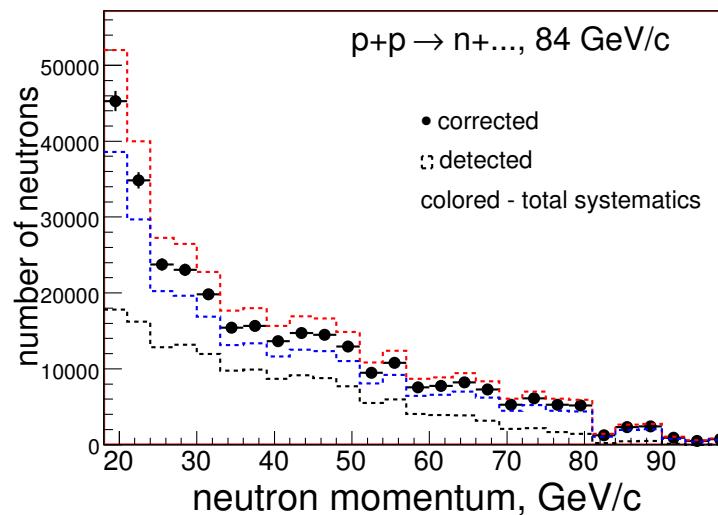
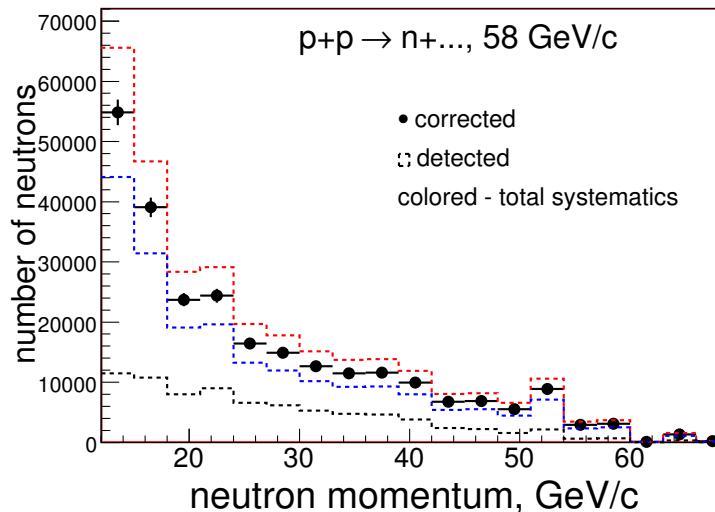
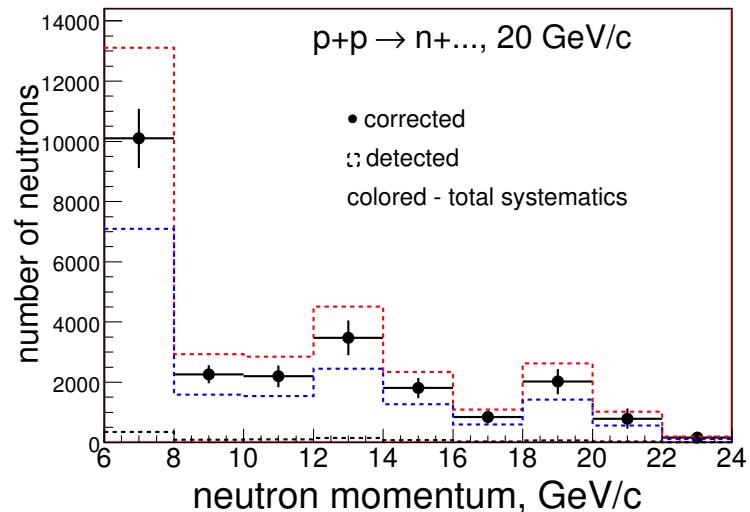
Table 7: Third column represents the N_n numbers for ±0.30×(corr-uncorr) variations in the correction value for the backgrounds. Last column - the systematic uncertainty.

total systematic uncertainty

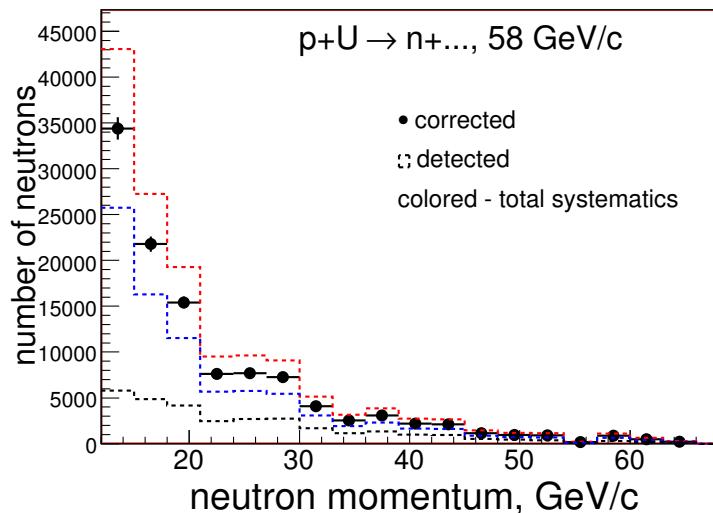
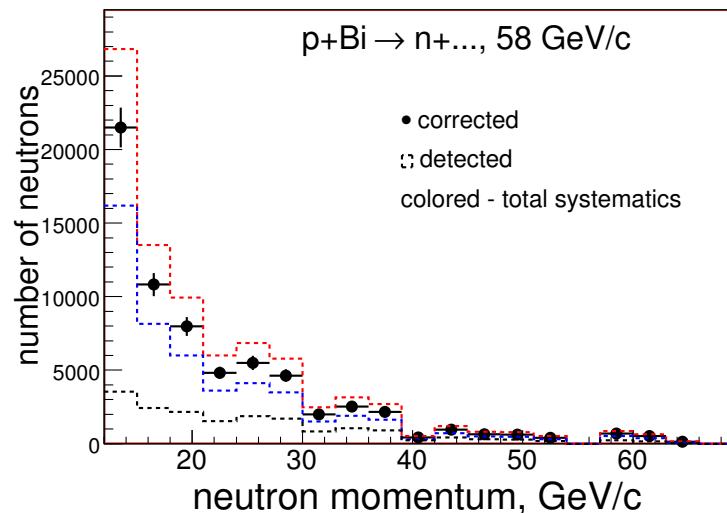
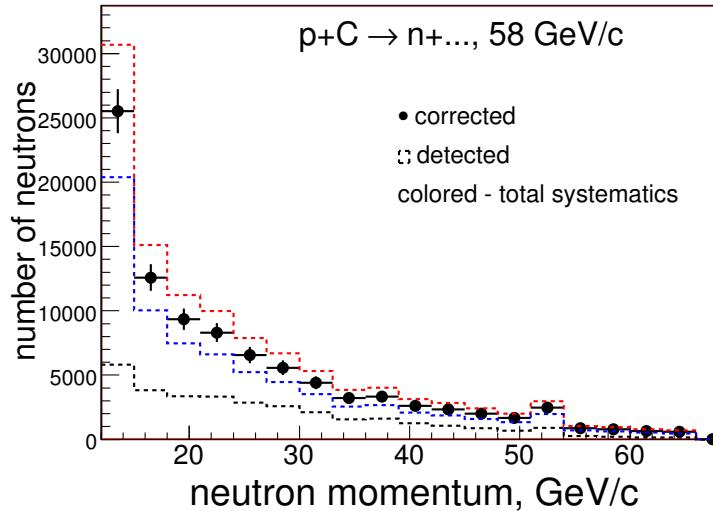
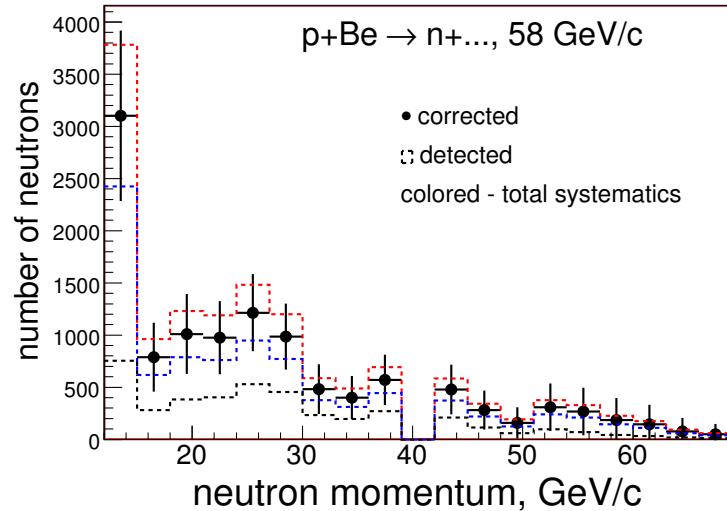
tgt-p _{beam}	Inc	T-out.	Trig.	Accept	Cuts	Backgr	Total
H ₂ -20	±0.10	±0.050	±0.053	±0.263	±0.064	±0.002	±0.298
H ₂ -58	±0.10	±0.051	±0.028	±0.149	±0.041	±0.031	±0.196
Be-58	±0.10	±0.112	±0.017	±0.153	±0.030	±0.027	±0.219
C-58	±0.10	±0.043	±0.013	±0.165	±0.029	±0.024	±0.202
Bi-58	±0.10	±0.091	±0.014	±0.203	±0.023	±0.032	±0.247
U-58	±0.10	±0.098	±0.013	±0.204	±0.023	±0.034	±0.251
H ₂ -84	±0.10	±0.045	±0.027	±0.082	±0.034	±0.037	±0.148
Be-120	±0.10	±0.068	±0.009	±0.057	±0.031	±0.071	±0.155
C-120	±0.10	±0.036	±0.005	±0.060	±0.029	±0.063	±0.140
Bi-120	±0.10	±0.108	±0.014	±0.095	±0.025	±0.081	±0.195

Table 8: The specific and total systematic uncertainties. The total was calculated by adding the specific in quadrature. Do we like to reconsider the systematics for incident proton sample size?

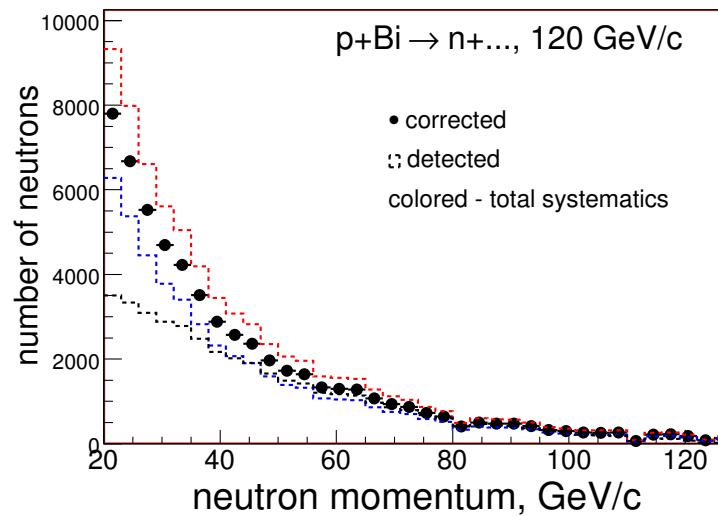
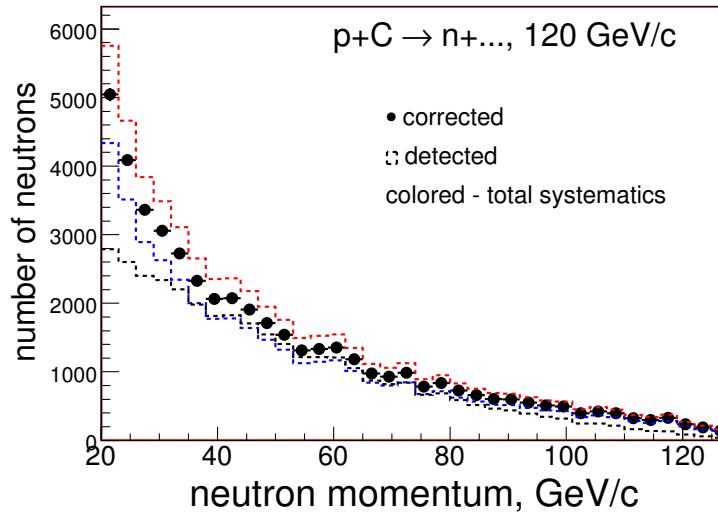
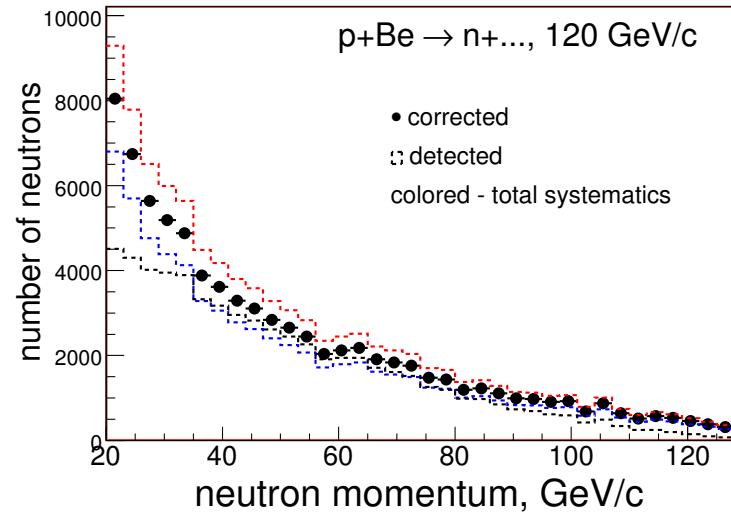
systematics sizes for p+p interactions



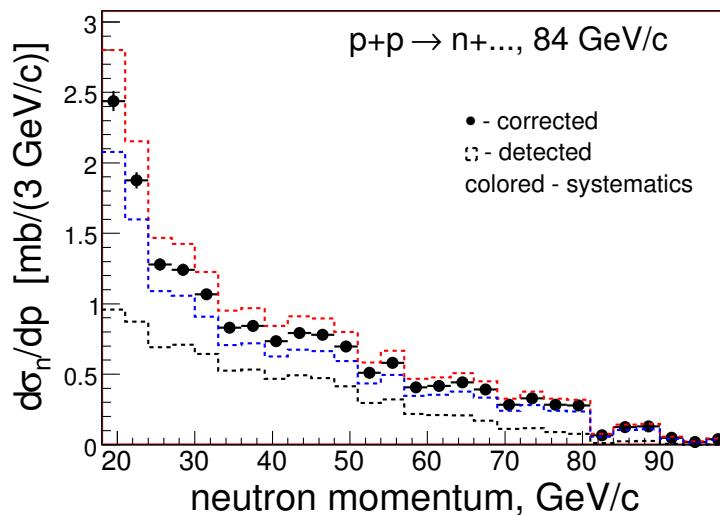
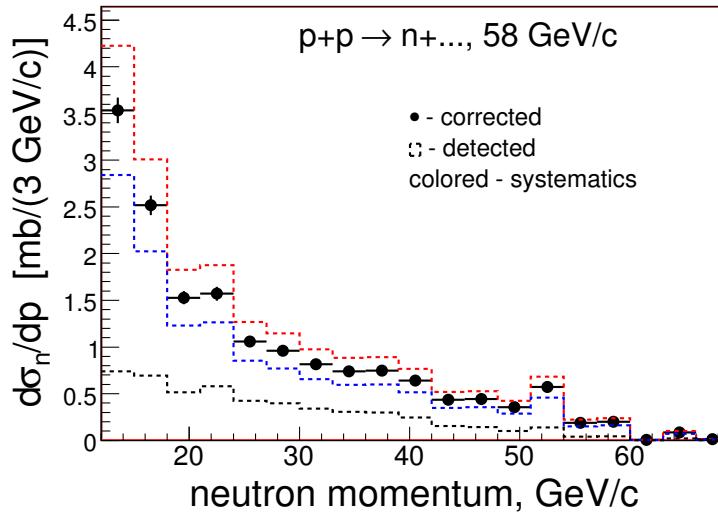
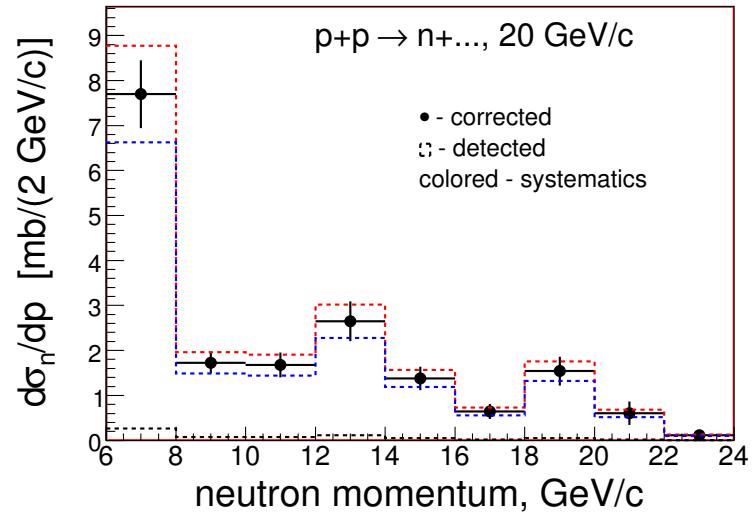
systematics sizes for p+A interactions at 58 GeV/c



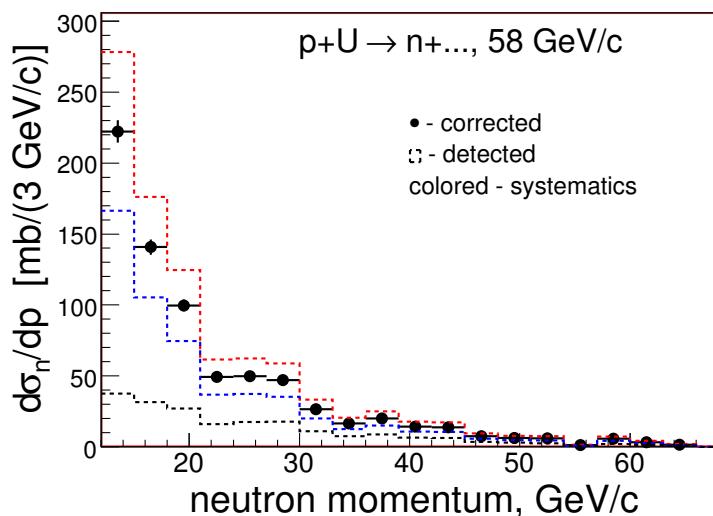
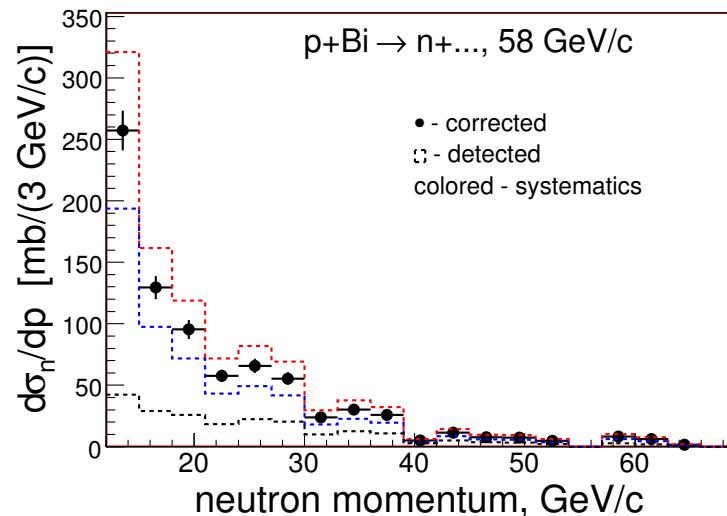
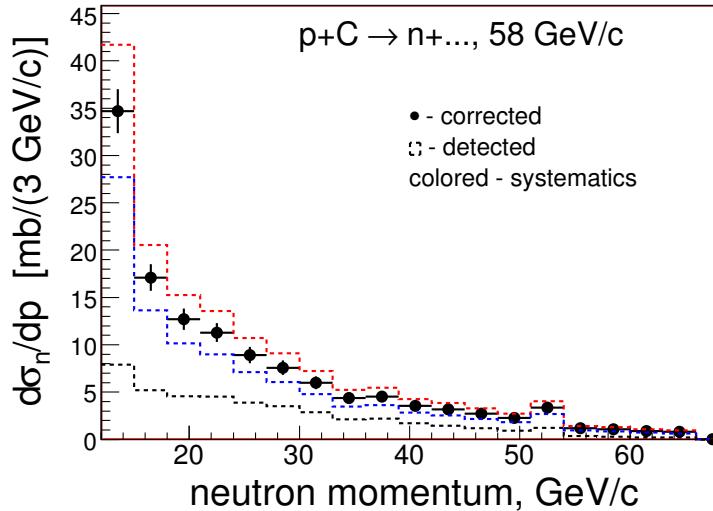
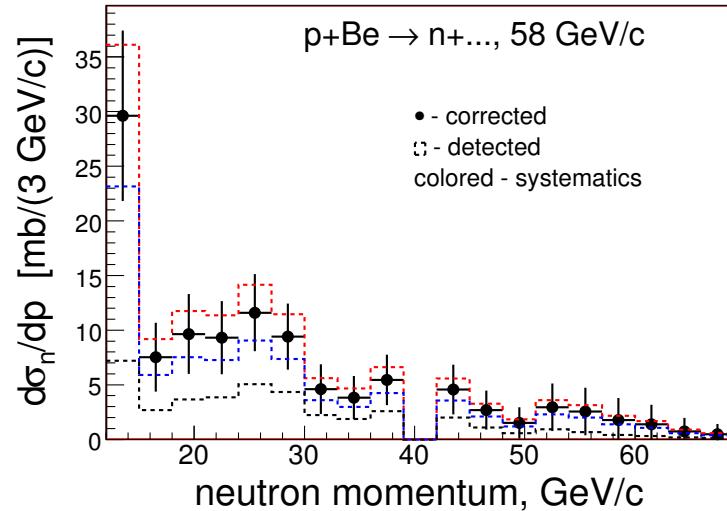
systematics sizes for p+A interactions at 120 GeV/c



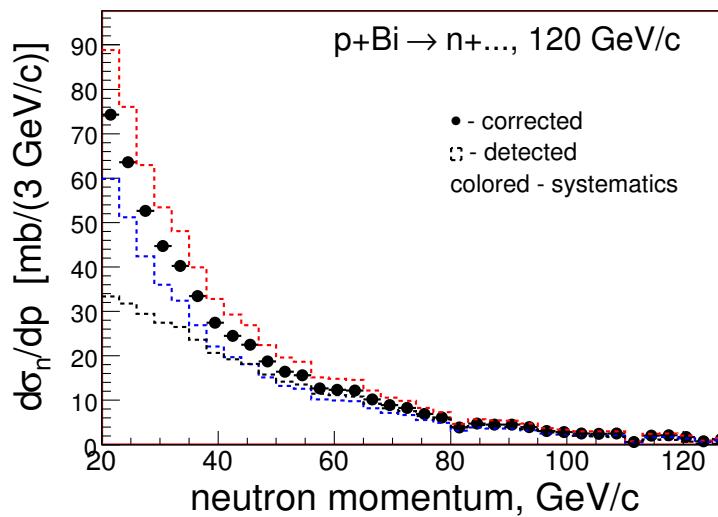
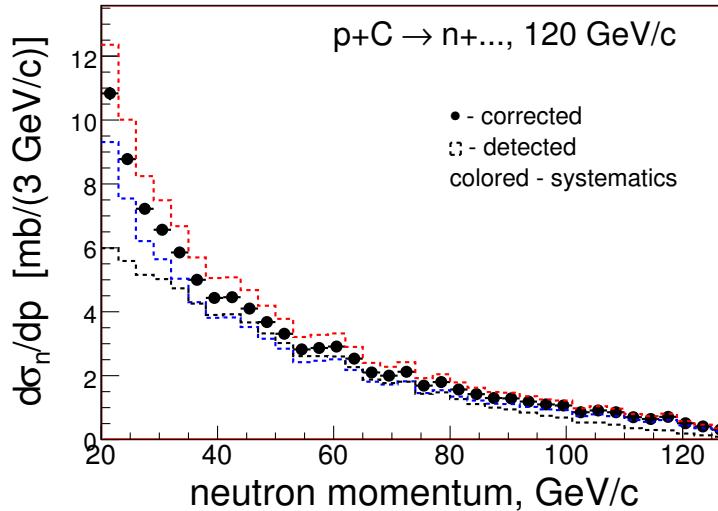
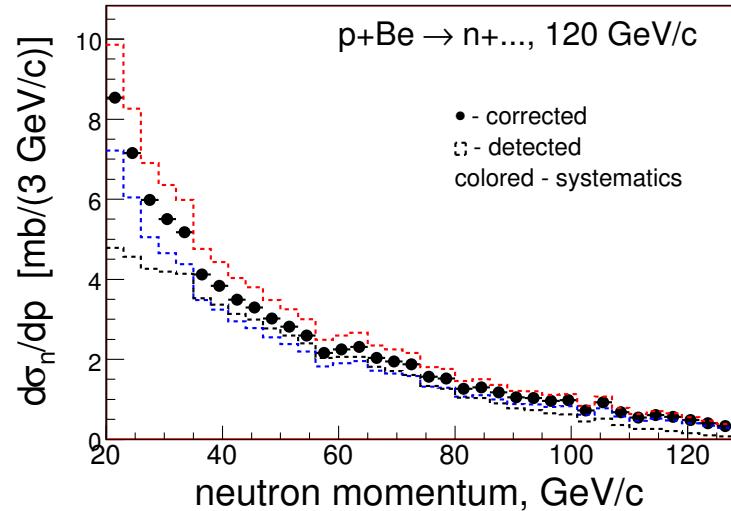
cross section for p+p interactions



cross section for p+A interactions at 58 GeV/c



cross section for p+A interactions at 120 GeV/c

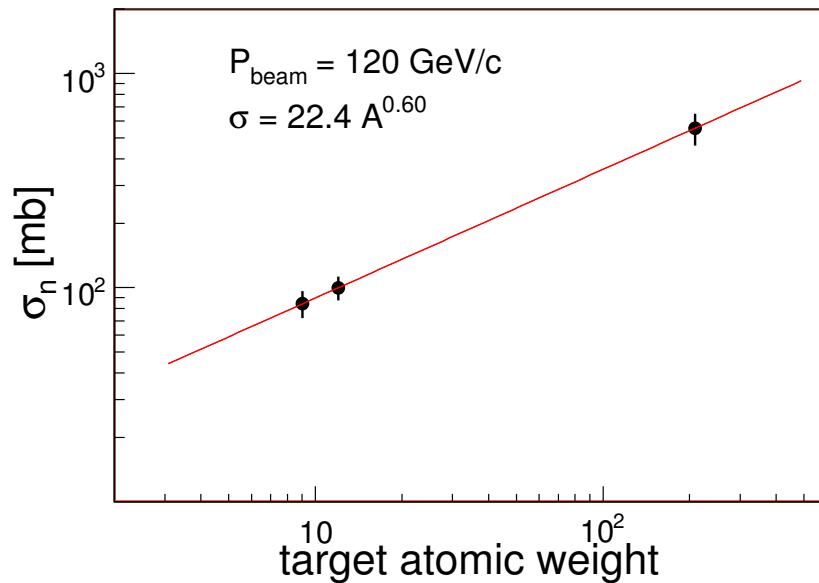
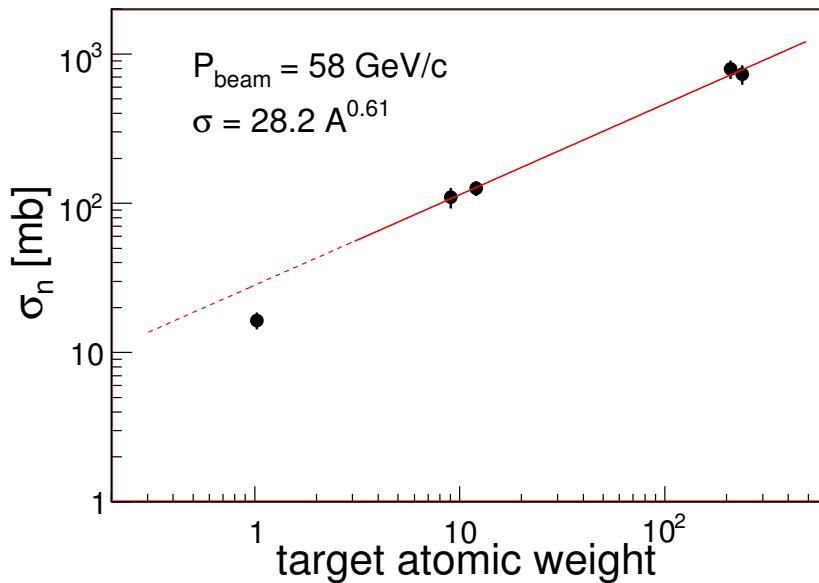


cross section - summary

tgt-p _{beam}	p_{min}	$\sigma_n(\text{detect})$	$\sigma_n(\text{corr})$	stat.	tot.syst.	syst-2
H ₂ -20	6	0.7	18.0	± 1.0	± 5.4	± 2.5
H ₂ -58	12	5.2	16.4	± 0.2	± 3.2	± 2.1
Be-58	12	39.8	109.6	± 6.5	± 24.0	± 17.1
C-58	12	44.3	126.2	± 3.0	± 25.4	± 14.6
Bi-58	12	213.7	792.9	± 18.0	± 196.2	± 112.2
U-58	12	199.5	730.3	± 10.0	± 183.4	± 107.0
H ₂ -84	18	8.7	16.9	± 0.2	± 2.5	± 2.1
Be-120	20	64.8	84.2	± 0.3	± 13.0	± 12.1
C-120	20	76.3	99.8	± 0.5	± 14.0	± 12.7
Bi-120	20	379.3	555.7	± 2.0	± 108.4	± 94.7

Table 9: The inclusive forward neutron production cross section with the $p_n > p_{min}$ neutron momentum threshold using p+A collisions at different momentum of the incident protons. The cross section units are in mbarn. Last column represents the total systematics without HCAL acceptance uncertainty included.

atomic weight dependence



The forward neutron production cross section as a function of the target atomic weight: 58 GeV/c (on left) and 120 GeV/c (on right), respectively. The H_2 data point (left) is not included to the fit. The errors - total syst. without HCAL part.

58 GeV/c	coefficient	power
Total systematics	28.4 ± 8.4	0.606 ± 0.075
w/o HCAL syst	28.2 ± 5.2	0.607 ± 0.046

Table 10: The fit parameters for 58 GeV/c data.

120 GeV/c	coefficient	power
Total systematics	22.4 ± 5.4	0.601 ± 0.074
w/o HCAL syst	22.4 ± 4.8	0.601 ± 0.065

Table 11: The fit parameters for 120 GeV/c data.

conclusions

- We presented the neutron production cross section results for given neutron momentum threshold using MIPP data.
- Major contribution to the systematic uncertainty are due to HCAL acceptance.
- Atomic weight dependences for 58 GeV/c and 120 GeV/c data are consistent to each other.

Next meeting: answers for the questions and comments.

Back-up plots, tables

Neutron sample size

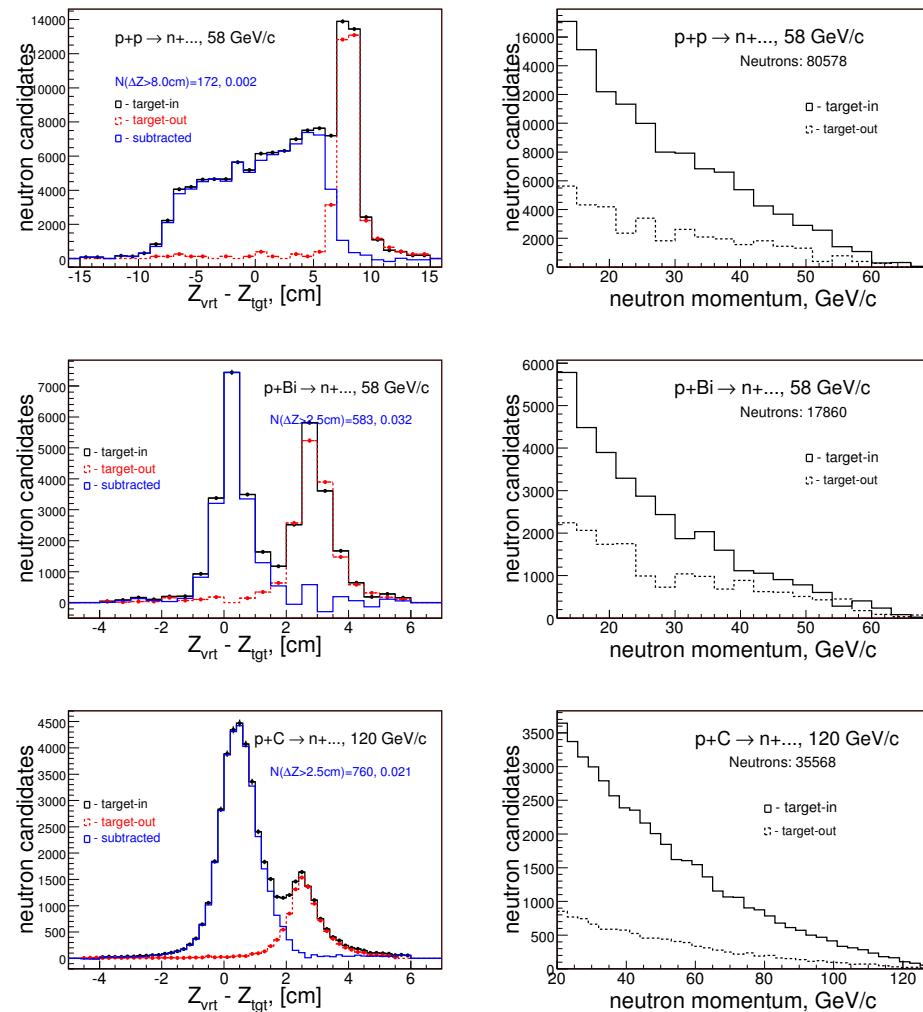
Tgt-p _{beam}	n _n (t-in)-n _n (t-out)	-Backgr	$\frac{1}{\epsilon(\text{trig})}$	$\frac{1}{\epsilon(\text{hcal})}$	$\frac{1}{\epsilon(\text{cuts})}$	N _n (results)
H ₂ -20	886±48	-0.007	$\frac{1}{0.46}$	$\frac{1}{0.17}$	$\frac{1}{0.80}$	23649±1292
H ₂ -58	80578±1154	-0.08	$\frac{1}{0.71}$	$\frac{1}{0.52}$	$\frac{1}{0.87}$	254575±3646
Be-58	4164±247	-0.08	$\frac{1}{0.82}$	$\frac{1}{0.49}$	$\frac{1}{0.91}$	11475±681
C-58	32589±773	-0.07	$\frac{1}{0.84}$	$\frac{1}{0.48}$	$\frac{1}{0.90}$	92874±2204
Bi-58	17861±405	-0.10	$\frac{1}{0.845}$	$\frac{1}{0.35}$	$\frac{1}{0.92}$	66279±1503
U-58	30864±421	-0.11	$\frac{1}{0.845}$	$\frac{1}{0.35}$	$\frac{1}{0.92}$	113005±1541
H ₂ -84	161097±1517	-0.12	$\frac{1}{0.73}$	$\frac{1}{0.68}$	$\frac{1}{0.89}$	314452±2962
Be-120	61047±199	-0.19	$\frac{1}{0.885}$	$\frac{1}{0.84}$	$\frac{1}{0.90}$	79377±258
C-120	35568±165	-0.17	$\frac{1}{0.905}$	$\frac{1}{0.83}$	$\frac{1}{0.90}$	46493±216
Bi-120	39825±146	-0.22	$\frac{1}{0.87}$	$\frac{1}{0.71}$	$\frac{1}{0.92}$	58341±214

Table 12: Summary of corrections to the neutron sample size. Uncertainties are statistical.

Target-out subtraction

target	p_{beam}	CF_{t-out}
H ₂	20	0.50
H ₂	58	1.16
Be	58	1.47
C	58	1.39
Bi	58	1.14
U	58	1.09
H ₂	84	1.11
Be	120	1.09
C	120	1.25
Bi	120	1.04

Table 13: The correction factors for the target-out sample sizes.



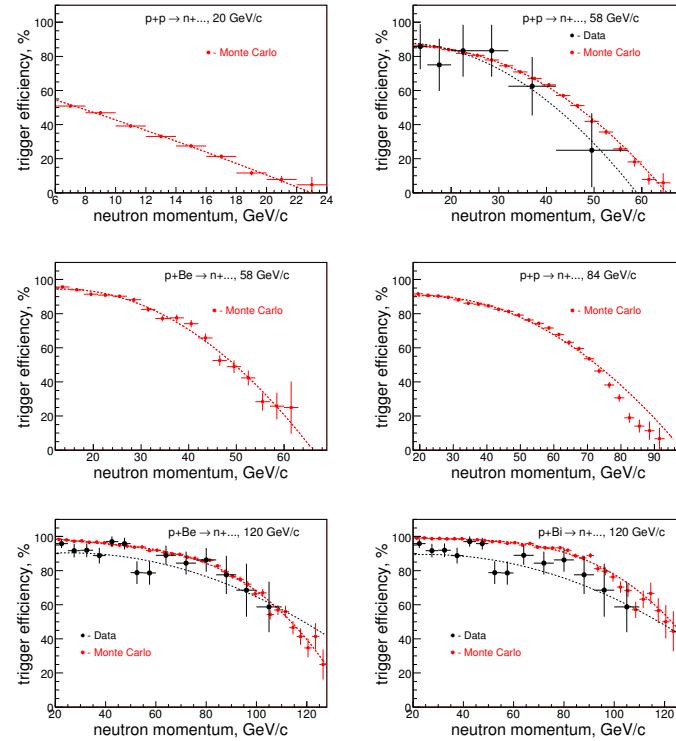
The vertex Z (on left) and measured neutron spectrum (on right) distributions. Plots illustrate the target-out contributions.

Trigger efficiency

- Use unbiased beam triggers and select neutrons
- Count SciHi trigger fires

tgt, p_b	N_n	$\epsilon_{trig}(\text{data})$	ϵ_{mc1}	ϵ_{mc2}	ϵ_{trig}^{avr}	ass_{syst}	M_{mc}^{dat}
H ₂ ,20	19	0.53±0.12	0.38 0.39		0.46	0.10	2.0 2.5
H ₂ ,58	43	0.67±0.07	0.72 0.74		0.71	0.10	4.9 4.6
Be, 58	3	1.00±?	0.83 0.82		0.82	0.10	n/a 5.9
C, 58	5	0.80±0.18	0.85 0.84		0.84	0.10	n/a 6.6
Bi, 58	9	0.67±0.16	0.91 0.91		0.845	0.10	n/a 9.8
U, 58	40	0.78±0.07	0.92 0.91		0.845	0.10	5.3 10.0
H ₂ ,84	137	0.66±0.04	0.82 0.80		0.73	0.10	
Be, 120	235	0.85±0.03	0.92 0.92		0.885	0.07	7.1 8.2
C, 120	129	0.88±0.03	0.93 0.93		0.905	0.05	7.7 9.3
Bi, 120	193	0.77±0.03	0.96 0.97		0.87	0.10	8.6 14.2

Table 14: Why trigger efficiency in MC is higher than in data? Answer: number of particles passing through scintillator in MC is higher (last column).

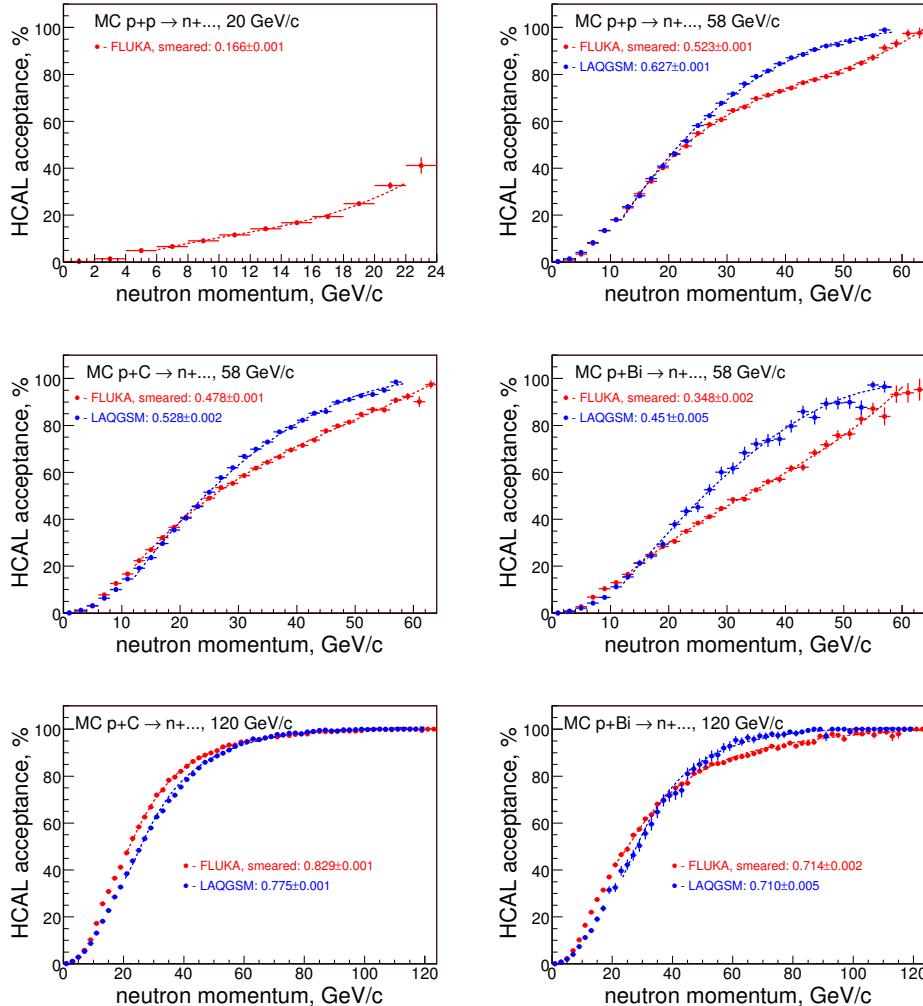


How it was applied to data?

The momentum dependence follows according to Monte Carlo prediction (red dashed curve).

The level of each predicted curve was adjusted. For an example, Bi-58 efficiency in each bin has been multiplied by factor 0.845/0.91

Hadron calorimeter acceptance, results



HCAL acceptance as function of the smeared neutron momentum.

October plots: ..as function of the summed neutron momentum.

p_{beam}	FLUKA	LAQGSM
H ₂ -20	0.166±0.001	-
H ₂ -58	0.523±0.001	0.627±0.001
Be-58	0.492±0.004	-
C-58	0.478±0.001	0.528±0.002
Bi-58	0.348±0.002	0.451±0.005
U-58	0.349±0.002	-
H ₂ -84	0.680±0.001	-
Be-120	0.835±0.001	-
C-120	0.829±0.001	0.775±0.001
Bi-120	0.714±0.001	0.710±0.001

Table 15: Average HCAL acceptances.

Functions (red dashed curves) were applied for data to take in account the HCAL acceptance.